Photographic Tone Reproduction for Digital Images

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Tone Reproduction Problem

- Watch the light
- Compare with projection on screen

Overview

- Tone reproduction is difficult when
  - Dynamic range is high
  - Algorithm is used in predictive context
- Requirements of a practical operator
- Skip many details (see paper for those)

Dynamic Range

- Ratio of brightest and darkest regions **where detail is visible**
- Implies that some controlled burn-out is desirable!
- Simplifies tone reproduction problem

Controlled Burn-out is OK

No detail expected when looking into the sun (sunspots)

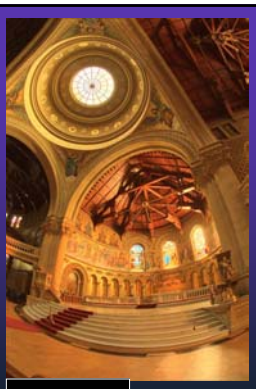
Zones

Lin:	1	2	4	8	16	32	64	128	256
Log:	1	2	3	4	5	6	7	8	9

- Each doubling of intensity is new zone
- Nine zones with visible detail can be mapped to print, fewer to displays
- Zones are a good measure of dynamic range

Typical Dynamic Ranges

- Photographs: 4-6 zones with visible detail (after digitizing)
- HDR images: 7-11 zones with visible detail
- Tone reproduction should not be very difficult for most images!



11 Zones

7 Zones

Rest of Talk:

- A very simple global operator adequate for most images (up to 11 zones)
- A local operator that handles very high dynamic range images (12 zones and more)

Global vs. Local

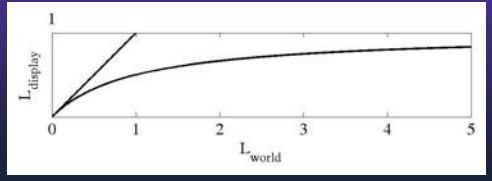
- Global
  - Scale each pixel according to a fixed curve
  - Key issue: shape of curve
- Local
  - Scale each pixel by a local average
  - Key issue: size of local neighborhood

Global Operator

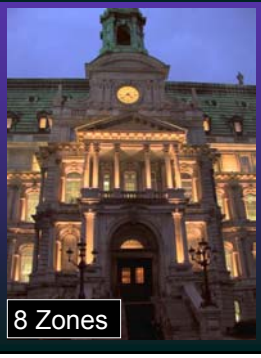
- Compression curve needs to
  - Bring everything within range
  - Leave dark areas alone
- In other words
  - Asymptote at 1
  - Derivative of 1 at 0

Global Operator

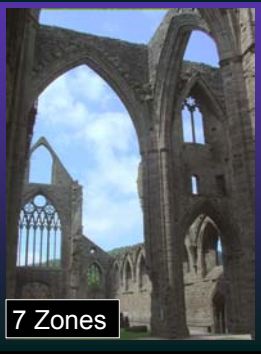
$$L_{display} = \frac{L_{world}}{1 + L_{world}}$$



Global Operator Results

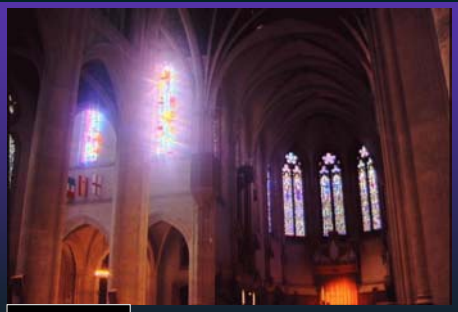


8 Zones



7 Zones

Global Operator Results



12 Zones

Global Operator Results

15 Zones

Local Operator

- Replace $L_{display} = \frac{L_{world}}{1 + L_{world}}$
- With $L_{display} = \frac{L_{world}}{1 + V_1}$
- V1 is our dodge-and-burn operator

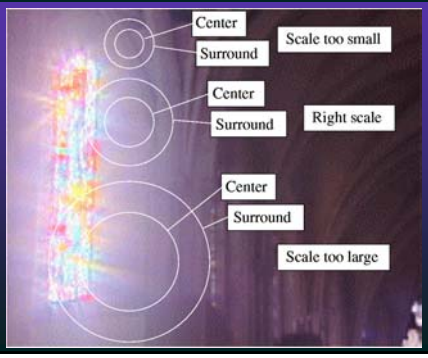
Dodge and Burn

- Roughly equivalent to local adaptation
- Compute by carefully choosing a local neighborhood for each pixel
- Then take a local average of this neighborhood (which is V1)

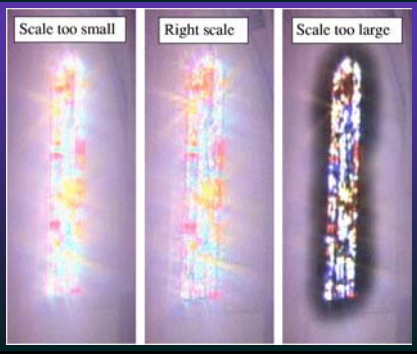
Dodge and Burn Computation

- Compute Gaussian blurred images at different scales (sizes)
- Take difference of Gaussians to detect high contrast (Blommaert model)
- Take Gaussian at largest scale that does not exceed contrast threshold (V1)

Size of Local Neighborhood



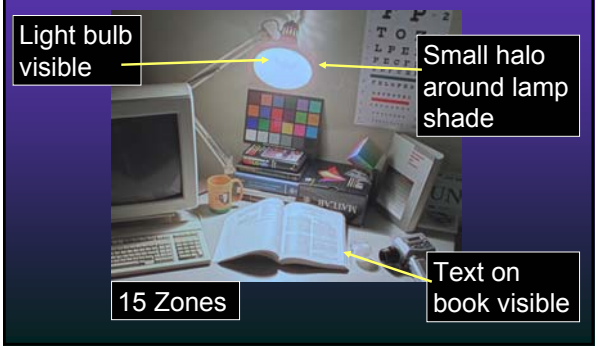
Size of Local Neighborhood



Subtleties

- Gaussians computed at relatively small scales
- For sufficient accuracy, computation rewritten in terms of the error function
- For sufficient speed, computation performed in Fourier domain

Local Operator Results



Conclusions

- Most "high dynamic range" images are medium dynamic range
- This makes tone reproduction a fairly straightforward problem for most practical applications/images

Conclusions

- Our global operator is very simple and is adequate for most images
- Our local operator is more involved and compresses very high dynamic range images adequately

Further Work

- Two manual parameters:
  - Key value to determine overall intensity of result
  - White point to fix contrast loss for low to medium dynamic range images
- Both can be automated with a straightforward algorithm – see forthcoming journal of graphics tools and my web page

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Erratum

Equation 1 in the paper should be:

$$L_w = \exp\left(\frac{1}{N}\sum_{x,y}\log\left(\delta + L_w(x,y)\right)\right)$$

Note: source code on CDROM is correct!

Informal comparison

Gradient-space [Fattal et al.] | Bilateral [Durand et al.] | Photographic [Reinhard et al.]

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